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**Mori et al.**

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(54) **METAL ELASTIC MEMBER, MINIATURE MACHINE, METHOD OF MANUFACTURING MINIATURE MACHINE, SWING CONTROL DEVICE AND SWING CONTROL METHOD**

(71) Applicant: **HOKUYO AUTOMATIC CO., LTD.**, Osaka (JP)

(72) Inventors: **Toshihiro Mori**, Takatsuki (JP); **Norihiro Asada**, Osaka (JP); **Kazuo Takai**, Sakai (JP)

(73) Assignee: **HOKUYO AUTOMATIC CO., LTD.**, Osaka (JP)

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***G02B 7/182*** (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ..... ***G02B 7/1821*** (2013.01); ***B81C 1/00674*** (2013.01); ***F16F 1/14*** (2013.01); ***G02B 26/0833*** (2013.01); ***H02K 33/02*** (2013.01); *B81B 2201/042* (2013.01); *B81B 2203/0154* (2013.01)

(58) **Field of Classification Search**
CPC .. G02B 6/0028; G02B 6/0088; G02B 21/002; G02B 21/26; G02B 26/105; G02B 26/0858; G02B 26/10; G02B 6/356; G02B 6/29311; G02B 6/29313; G02B 6/3588; G02B 6/3512; G02B 6/3584; G02B 7/1821; G02B 21/0028; G02B 26/127; G02B 27/0031; G02B 27/4227; G02B 27/4244
USPC ..... 318/119, 558, 686; 359/199.1, 199.3, 359/199.4; 310/36, 38; 267/154
See application file for complete search history.

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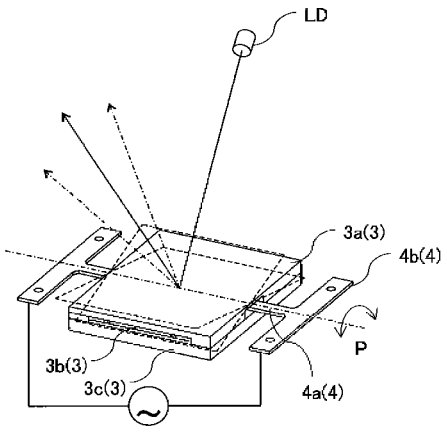
*Primary Examiner* — Bentsu Ro
(74) *Attorney, Agent, or Firm* — Oliff PLC

(57) **ABSTRACT**

A metal elastic member to be used for beams **4** for supporting a movable unit **3** at respective ends with respect to a fixed unit **2** in a miniature machine including at least one movable unit **3**, the fixed unit **2** and the beams **4** , and capable of swinging the movable unit about an axis P with the beams **4** serving as torsional rotation axes, includes a metal bar **4***a* having a predetermined length, a fixed unit pad **4***b* that is provided at a first end of the metal bar **4***a* and is fixed to the fixed unit **2**, and a movable unit pad **4***c* formed on the other end side of the metal bar **4***a* and fixed to the movable unit **3**. At least the metal bar **4***a* is molded to have a sectional area of 1 $mm^2$ or less by using a physical or chemical processing method excluding a mechanical processing method and swings the movable unit **3** within a frequency of 150 Hz to 500 Hz.

**13 Claims, 15 Drawing Sheets**



(51) **Int. Cl.**

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| ***F16F 1/14*** | (2006.01) |
| ***H02K 33/02*** | (2006.01) |
| ***G02B 26/08*** | (2006.01) |
| ***B81C 1/00*** | (2006.01) |

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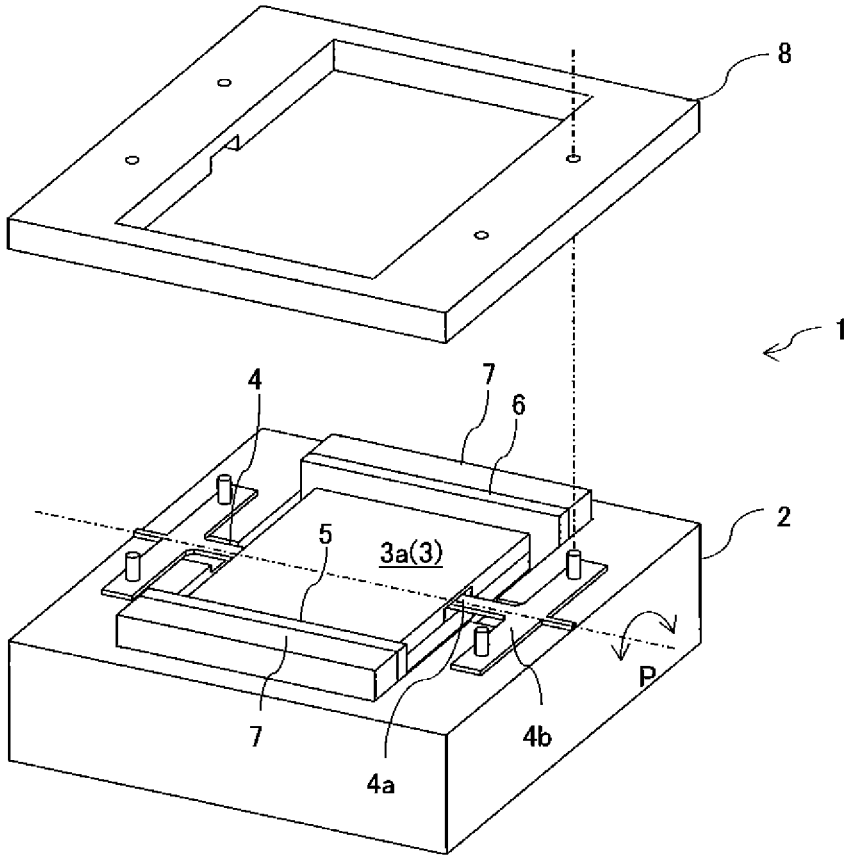



Fig.1

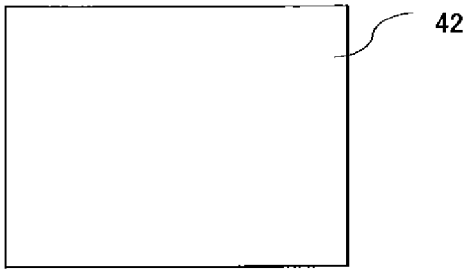



Fig.2A

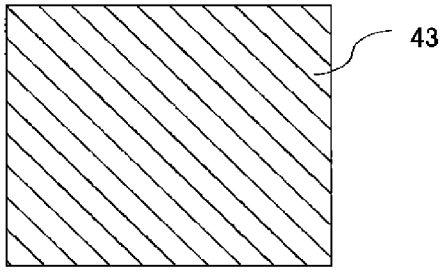



Fig.2B

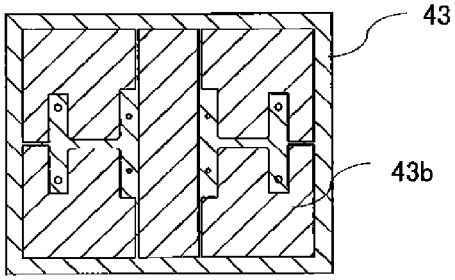



Fig.2C

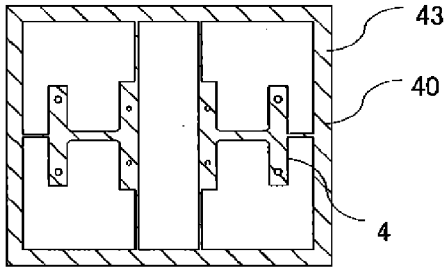



Fig.2D

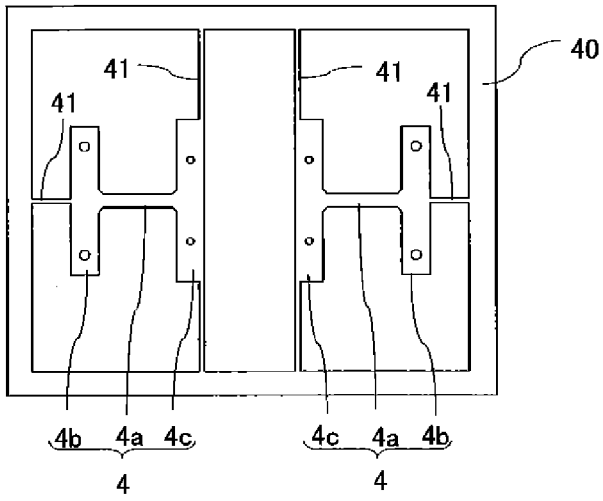



Fig.2E

Fig.3A

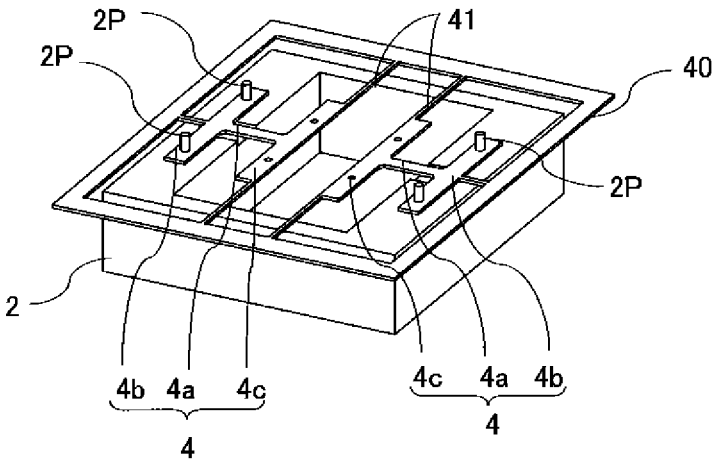



Fig.3B

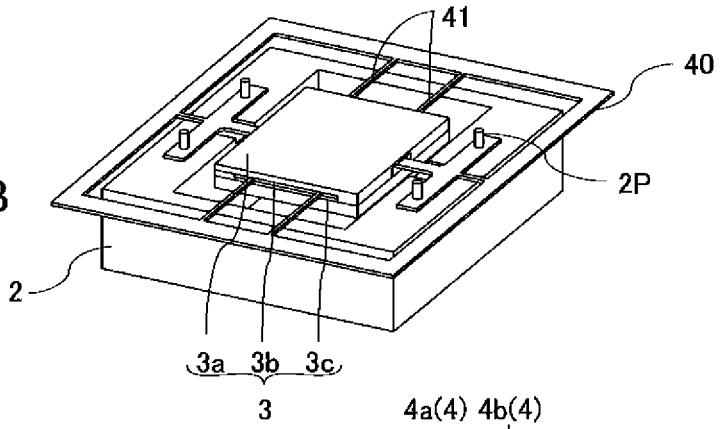
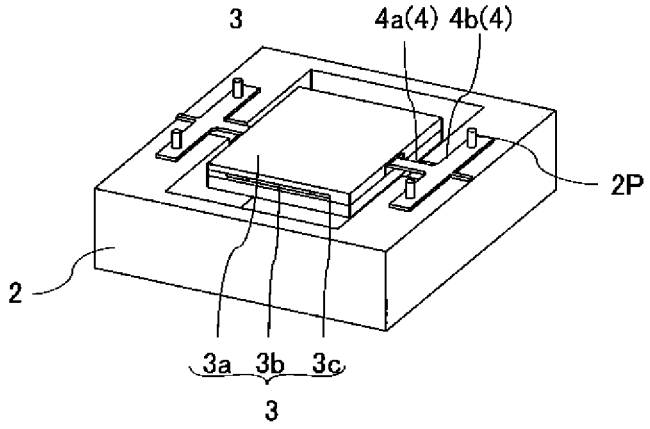



Fig.3C



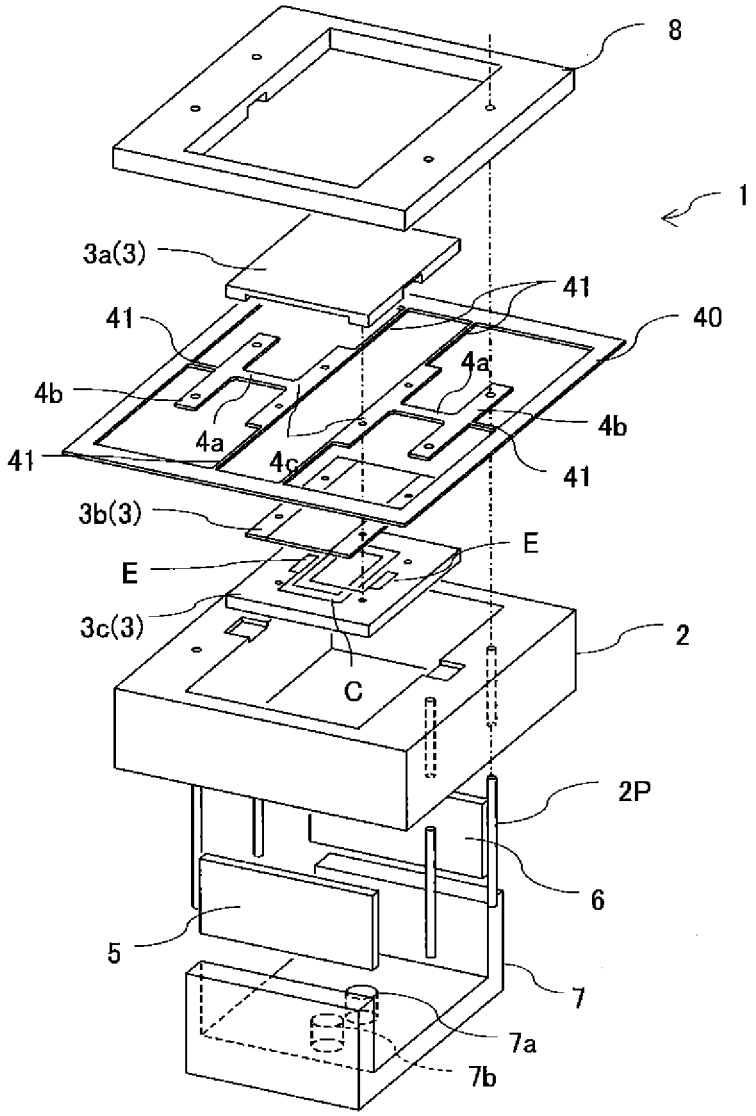



Fig.4

Fig.5A

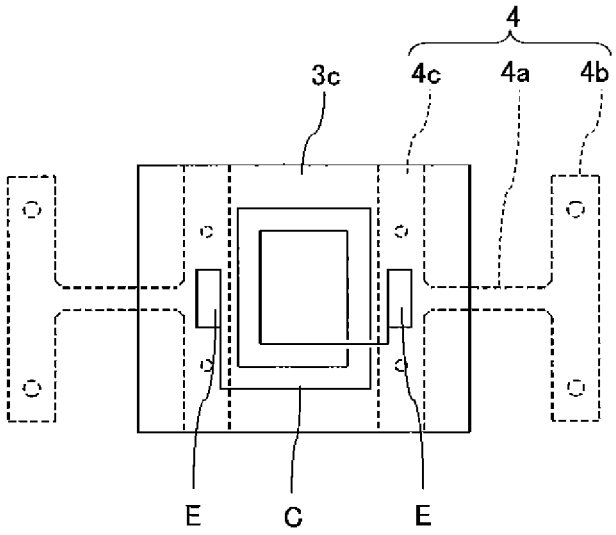



Fig.5B

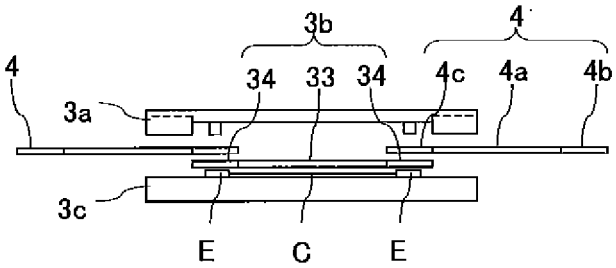
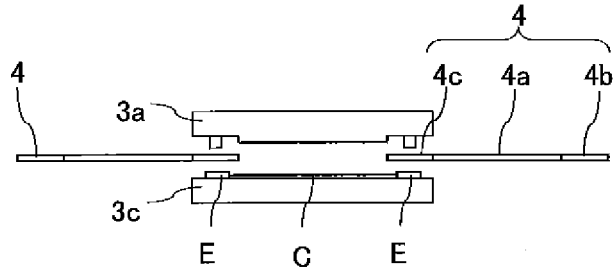



Fig.5C



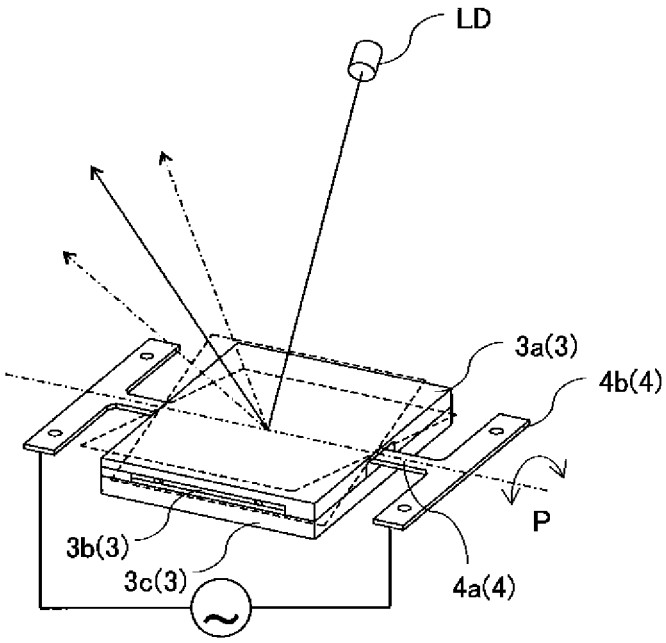



Fig.6

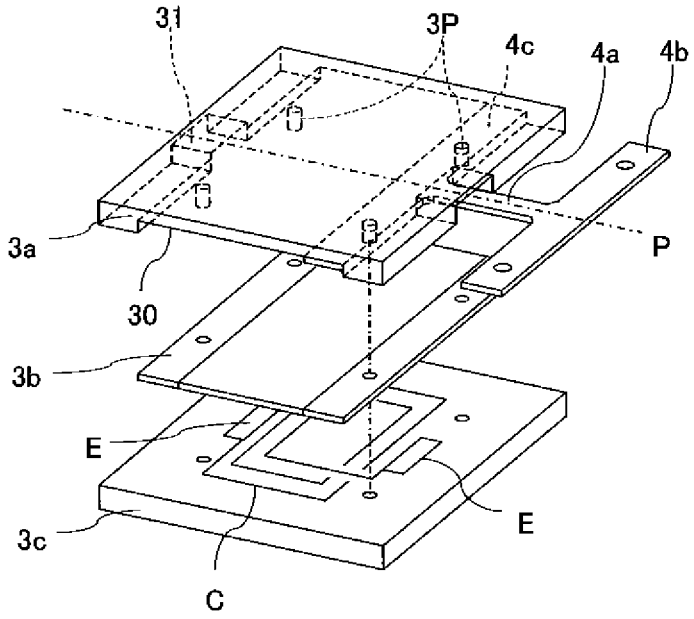



Fig.7

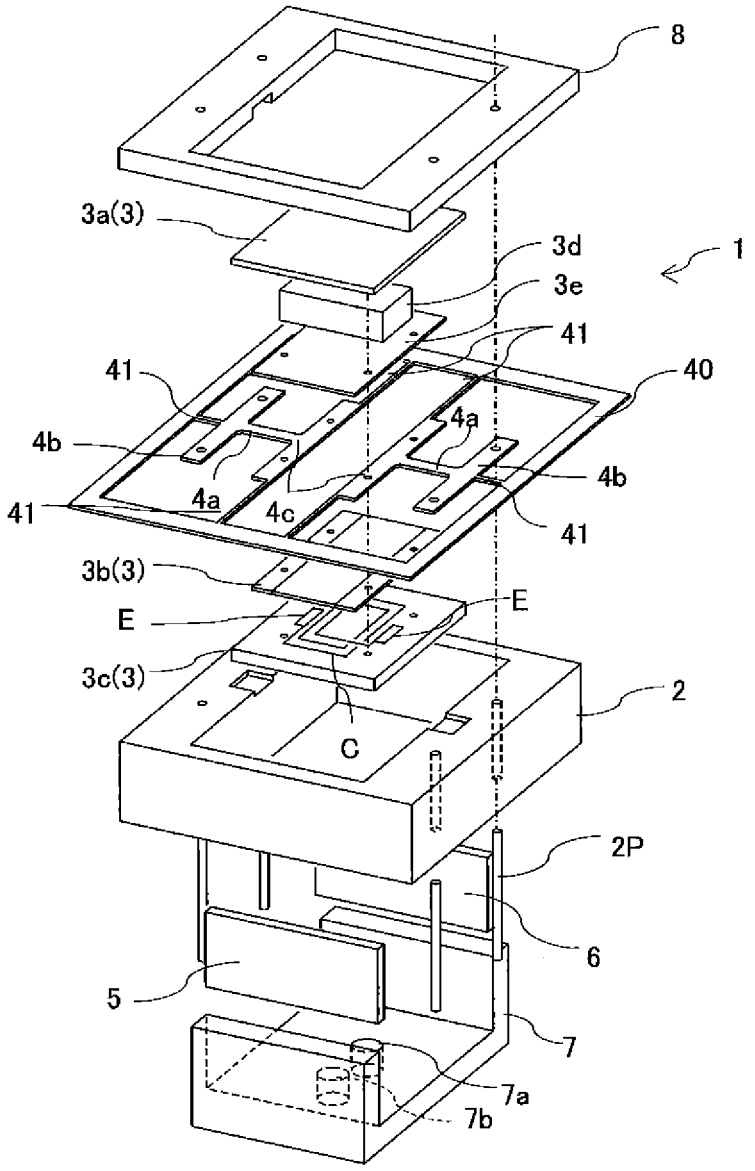



Fig.8

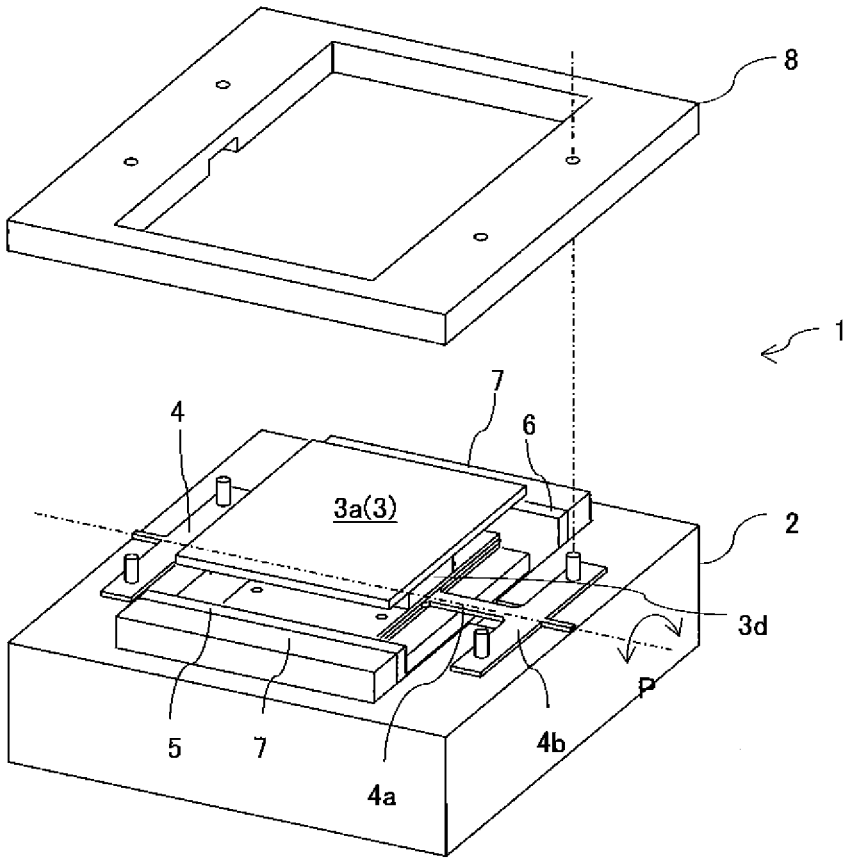



Fig.9

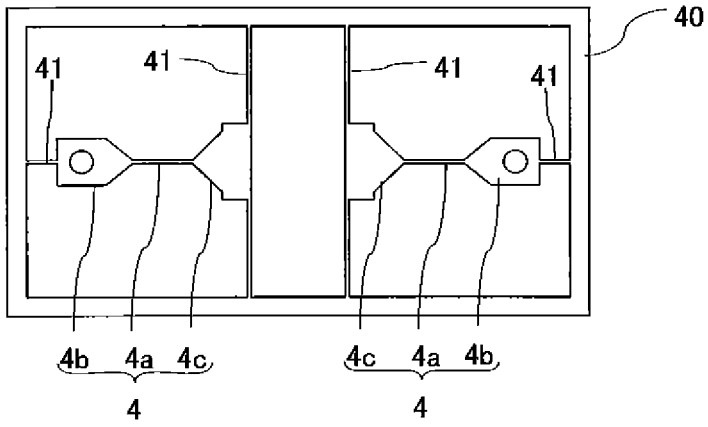



Fig.10

Fig.11A

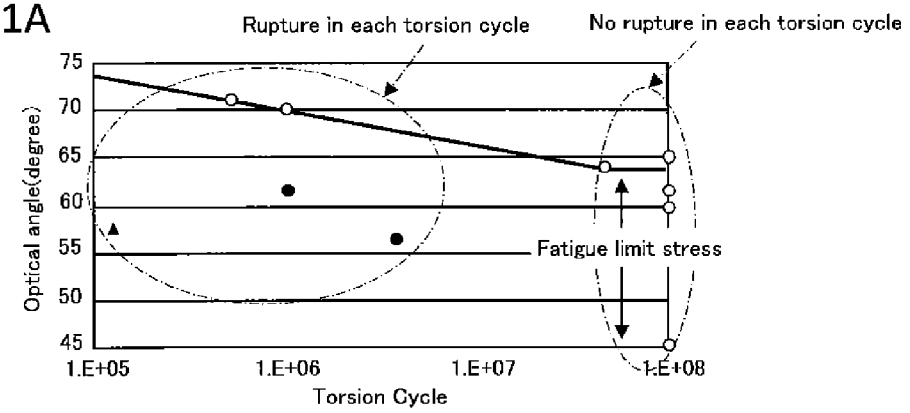



Fig.11B

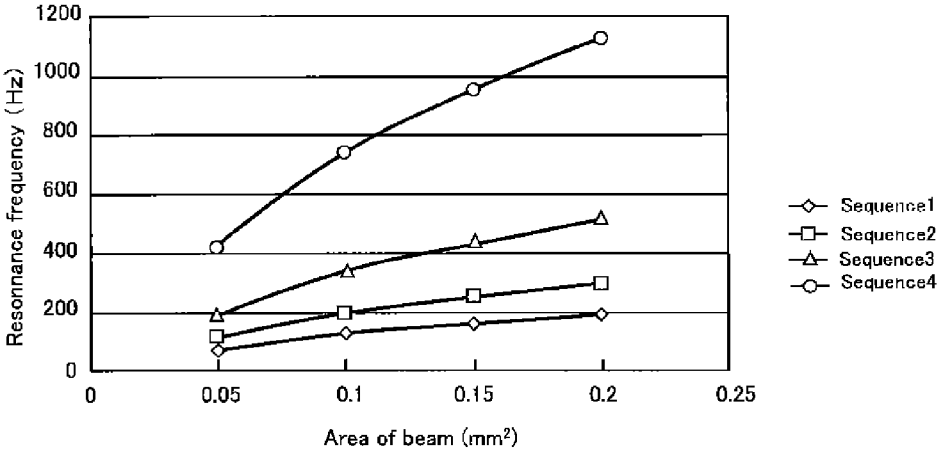
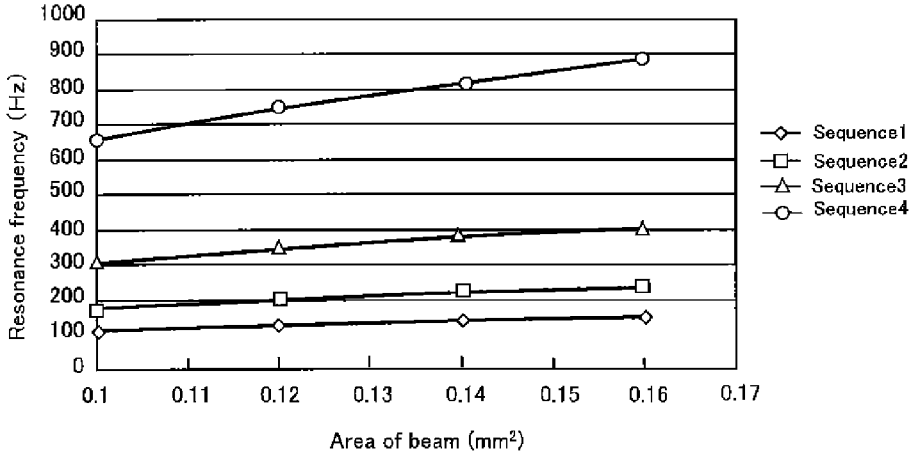



Fig.11C



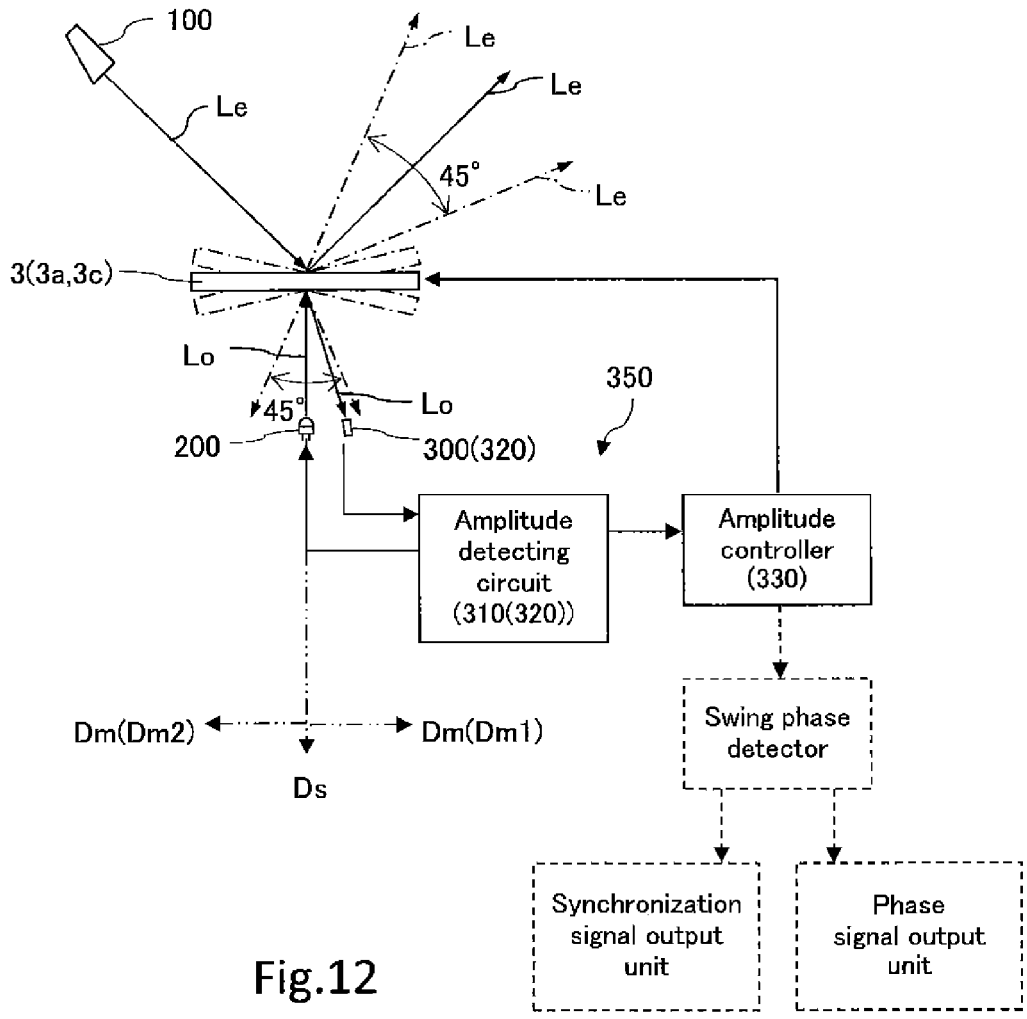

100
Le
Le
Le
Le
45°
3(3a,3c)
Lo
45°
Lo
200
300(320)
350
Amplitude detecting circuit (310(320))
Amplitude controller (330)
Swing phase detector
Dm(Dm2)
Dm(Dm1)
Ds
Synchronization signal output unit
Phase signal output unit

Fig.12

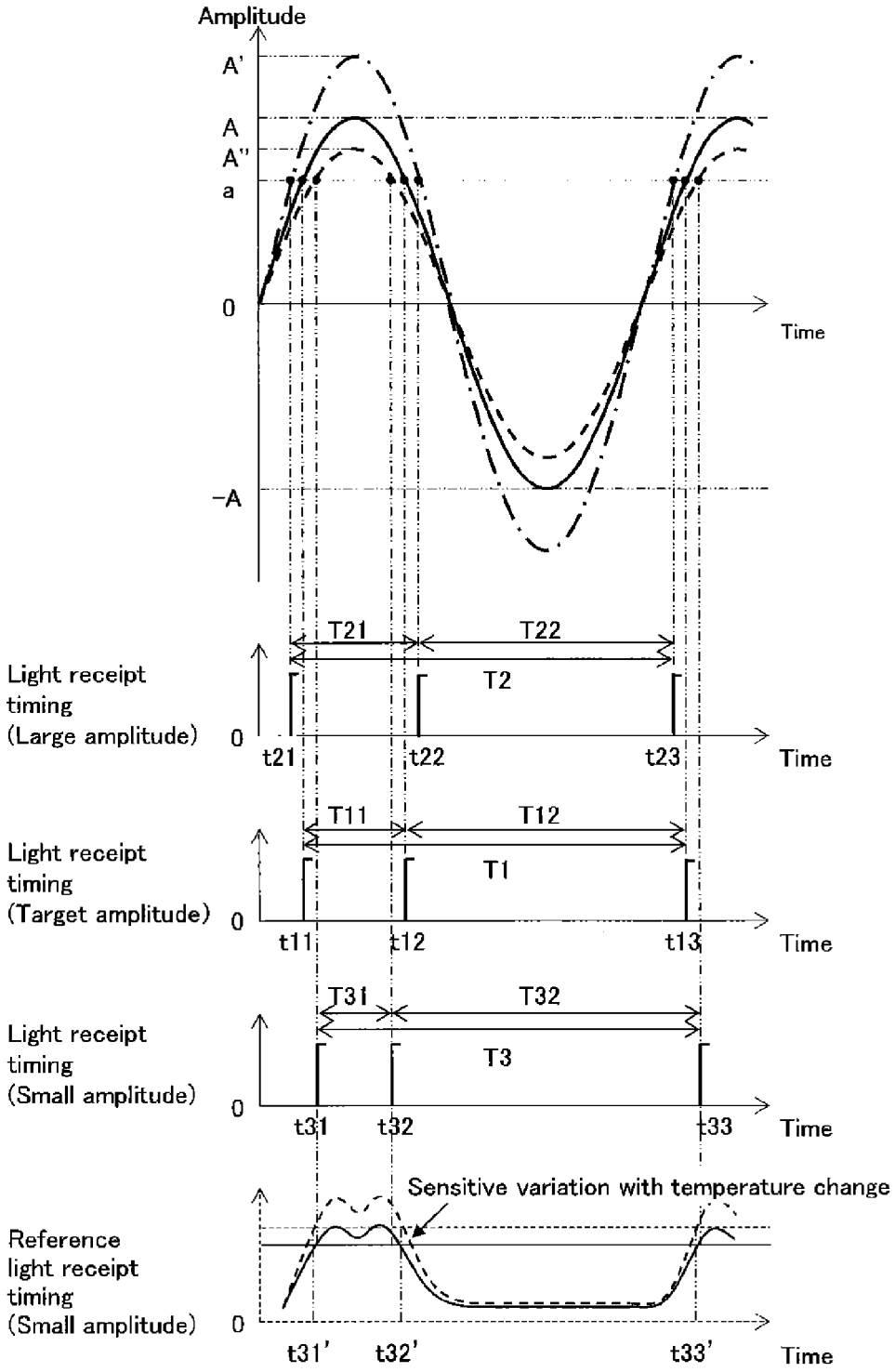

Amplitude
A'
A
A''
a
0
Time
-A
T21
T22
T2
Light receipt timing (Large amplitude)
0
t21
t22
t23
Time
T11
T12
T1
Light receipt timing (Target amplitude)
0
t11
t12
t13
Time
T31
T32
T3
Light receipt timing (Small amplitude)
0
t31
t32
t33
Time
Sensitive variation with temperature change
Reference light receipt timing (Small amplitude)
0
t31'
t32'
t33'
Time

Fig.13

Fig.14A

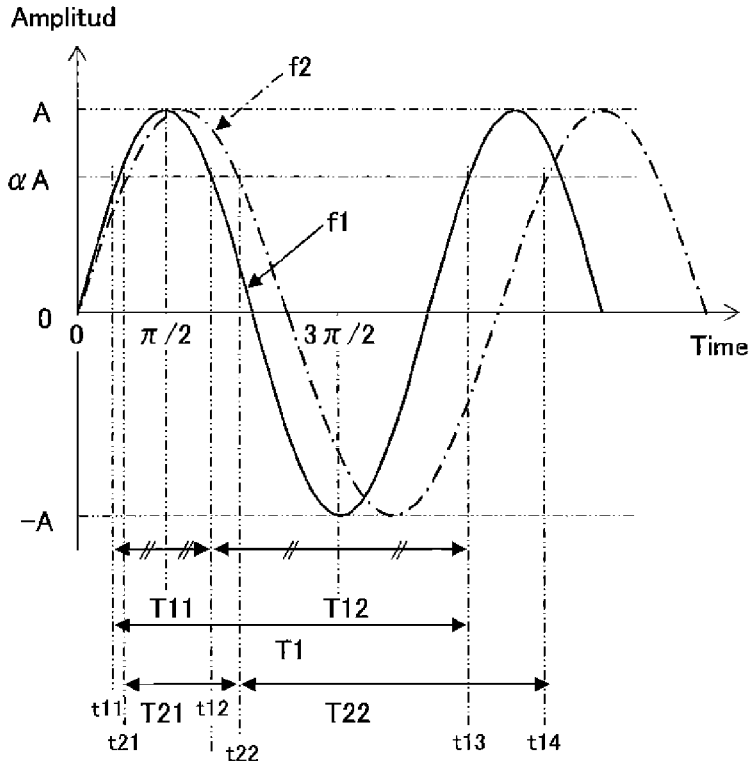
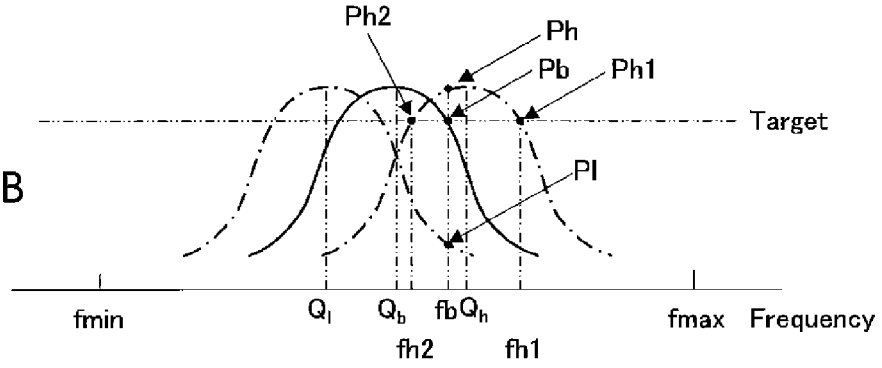



Fig.14B



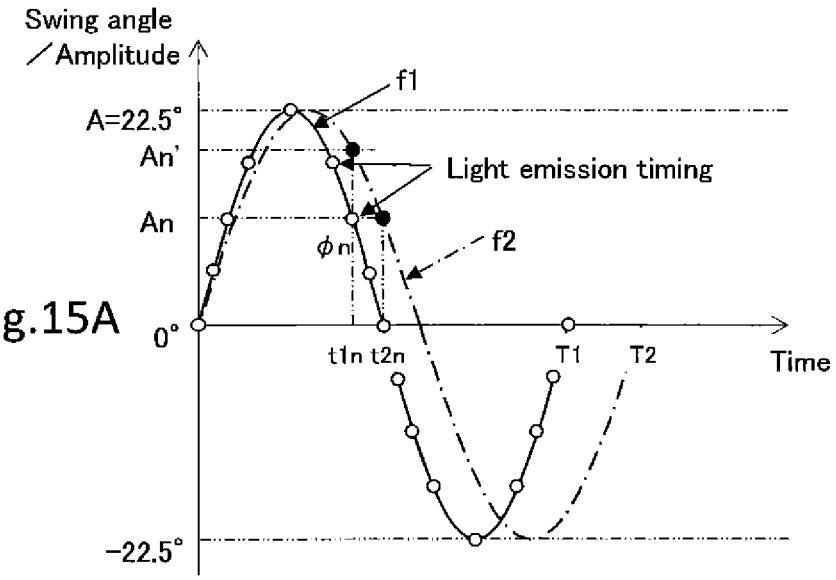



Fig.15A

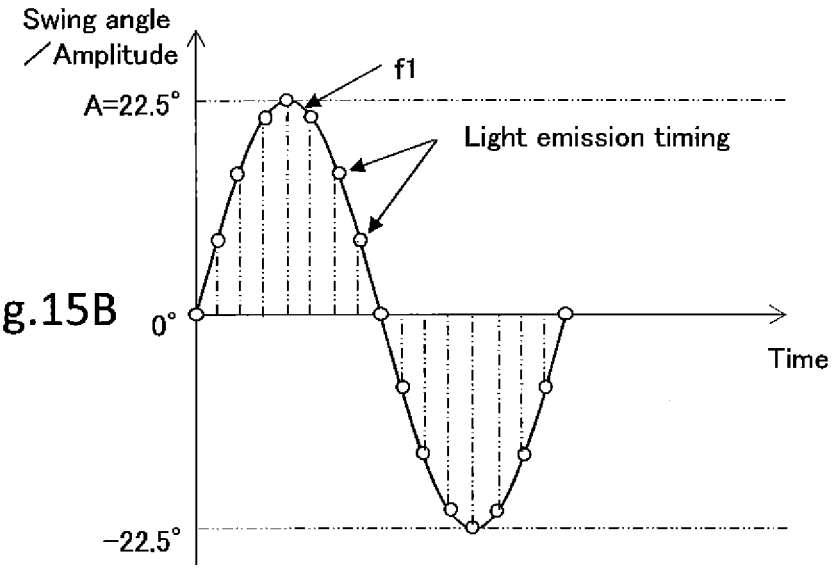



Fig.15B

# METAL ELASTIC MEMBER, MINIATURE MACHINE, METHOD OF MANUFACTURING MINIATURE MACHINE, SWING CONTROL DEVICE AND SWING CONTROL METHOD

This application is based on an application No. 2012-247796 filed in Japan, the contents of which are hereby incorporated by reference.

## BACKGROUND OF THE INVENTION

1. Field of the invention

The present invention relates to a metal elastic member, a miniature machine, a method of manufacturing a miniature machine, a swing control device, and a swing control method, and, for example, relates to a metal elastic member, a miniature machine, a method of manufacturing a miniature machine, a swing control device, and a swing control method which are used for repetitively scanning light within a predetermined angle range.

2. Description of the related art

A miniature machine such as a scanning light deflection element to be manufactured by using the MEMS (Micro Electro Mechanical Systems) technique includes at least one movable unit, a fixed unit, and paired beams for supporting the movable unit at the respective ends with respect to the fixed unit. The movable unit is supported by the fixed unit so as to be swingable about an axis with paired beams serving as torsional rotation axes. In other words, the beams serve as torsion beams in a gimbal structure.

For example, in a miniature machine in which the movable unit is configured by a light deflecting mirror for deflecting and scanning incident light and a flat coil formed on a back face of the light deflecting mirror and paired permanent magnets are disposed in the fixed unit so as to have the coil sandwiched therebetween, Lorentz force generated by an alternating current flowing to the coil and a magnetic field formed by the permanent magnets acts on the coil so that the movable unit supported by the beams, that is, the light deflecting mirror is repetitively swung.

Japanese Unexamined Patent Publication No. 2003-84226 proposes an optical scanner having a movable unit and a beam formed integrally by applying a semiconductor manufacturing technique to a single crystal silicon substrate.

Japanese Unexamined Patent Publication No. 9-281417 proposes a micro mirror device in which a beam is fabricated by using a conductive amorphous aluminum alloy in a monolithic manufacturing process.

Japanese Unexamined Patent Publication No. 2009-175368 proposes a vibration mirror including a beam obtained by pressing pure titanium or a titanium alloy.

Japanese Unexamined Patent Publication No. 2008-40228 discloses a miniature machine including a beam formed by a conductive polymer as a suitable beam for driving a movable unit at a low frequency of 150 Hz or less. The miniature machine is used for a bar code reader or the like and serves to scan measurement light at a light deflection angle of approximately 50°.

Moreover, Japanese Unexamined Patent Publication Nos. 2004-258548 and 2012-170196 disclose a control method of variably controlling the value of current applied to a coil in order to control to swing the movable unit of the miniature machine at certain amplitude.

In a case where there is configured a small-sized scanning type distance measuring device using the light deflecting mirror or an obstacle detecting device using the scanning type distance measuring device, it is necessary to swing a deflecting mirror of several mm square at a comparatively low frequency of 150 Hz to 500 Hz, thereby scanning with measurement light within a scanning angle range of 45°, for example.



However, the beam fabricated by using a silicon material described in Japanese Unexamined Patent Publication No. 2003-84226 is a suitable material for a case where it is necessary to drive the movable unit at a comparatively high frequency, and has a problem in that stable driving cannot be carried out at a frequency of 500 Hz or less. Since the silicon material causes cleavage comparatively easily, moreover, there is also a problem in that the silicon material is hard to be used for a demand of a shock resistance.

The beam using the conductive amorphous aluminum alloy described in Japanese Unexamined Patent Publication No. 9-281417 has a problem in that the beam is fabricated in the monolithic manufacturing process so that a manufacturing cost is increased, and furthermore, has a problem in that the beam is hard to use in measurement requiring a beam diameter to some extent because a size including a light deflecting mirror of about 10 to 20 μm square is very small.

Referring to the beam obtained by pressing a metal described in Japanese Unexamined Patent Publication No. 2009-175368, a large number of minute concavo-convex portions or scratches are formed on a surface thereof in the working and stress concentrates depending on stress amplitude thereon. For this reason, there is a problem in that the minute concavo-convex portions or scratches act as starting points to grow a crack due to repetitive use and a fatigue failure thus tends to occur.

In particular, an optical scanner for scanning with measurement light to detect the presence of an obstacle based on reflected light corresponding to the measurement light is operated continuously for a long period of time. For this reason, even if the optical scanner is used at a frequency of 100 Hz, for example, it is necessary to resist stress amplitude three billion times per year.

For this reason, these metal components are usually subjected to a life test tens of thousands of times to hundreds of thousands of times or millions of times to tens of millions of times, and the life test for several tens of hours or several hundreds of hours in conversion into a time, and are used within a range in which a safety factor calculated based on the result is taken into consideration. In recent years, however, it is indicated that the safety factor is lacking in evaluation depending on stress amplitude millions of times to tens of millions of times.

A crack originating from a scratch on a surface or the like is referred to as a high cycle fatigue and a crack originating from a crystal defect in an inner part or the like is referred to as a Very High Cycle Fatigue, and a test hundreds of millions of times or billions of times of tests are required for evaluation. Consequently, a time required for the test also becomes enormous and it is actually difficult to guarantee a life to that extent.

The beam formed by a conductive polymer described in Japanese Unexamined Patent Publication No. 2008-40228 exhibits a preferred characteristic at a low frequency of 150 Hz or less. However, there is a problem in that stable driving cannot be carried out at a frequency of 150 Hz to 500 Hz, and a stress rupture is apt to be caused if hardness of a polymer is increased to aim at the stable driving.

As described in Japanese Unexamined Patent Publication Nos. 2004-258548 and 2012-170196, in the case where the value of current applied to the coil is variably controlled in order to control to swing the movable unit of the miniature machine at certain amplitude, there is required a complicated large-scale power supply circuit for accurately controlling the

applied current value including a factor for a change in a temperature characteristic of a circuit element or the like. Consequently, there is also a problem in that a cost is increased, and furthermore, a large installation space is required.

## SUMMARY OF THE INVENTION

It is an object of the present invention to provide a metal elastic member constituting a beam serving as a torsional rotation axis capable of swinging a movable unit within a comparatively low frequency range and having a long life and a high reliability, a miniature machine using the metal elastic member, a method of manufacturing the miniature machine, a swing control device, and a swing control method.

A characteristic structure of the metal elastic member according to the present invention is directed to a metal elastic member to be used for paired beams for supporting a movable unit at respective ends with respect to a fixed unit in a miniature machine including at least one movable unit, the fixed unit and the beams, and capable of swinging the movable unit about an axis with the beams serving as torsional rotation axes. The metal elastic member includes a metal bar having a predetermined length which swings the movable unit, a fixed unit pad that is provided at a first end of the metal bar and is fixed to the fixed unit, and a movable unit pad that is provided at a second end of the metal bar and is fixed to the movable unit, and at least the metal bar is molded to have a sectional area of 1 $mm^2$ or less by using a physical or chemical processing method excluding a mechanical processing method.

It is preferable that a frame, a pair of the metal bars disposed symmetrically on a straight line in the frame, and a plurality of support units for coupling the frame to each of the pads should be formed integrally by using the physical or chemical processing method excluding the mechanical processing method.

It is further preferable that the metal elastic member should be configured by any of metals including a stainless material, a carbon tool steel material, and a cold-reduced carbon steel sheet material which are rolled by a tension annealing method.

The physical or chemical processing method includes a focused ion beam method, an etching method and a plating method.

A characteristic structure of the miniature machine according to the present invention is directed to a miniature machine including at least one movable unit, a fixed unit and paired beams for supporting the movable unit at the respective ends with respect to the fixed unit, and capable of swinging the movable unit about an axis with the beams serving as torsional rotation axes, and the beams include a metal bar which is molded to have a sectional area of 1 $mm^2$ or less by using a physical or chemical processing method excluding a mechanical processing method and swings the movable unit.

Moreover, it is preferable that a coil should be formed in the movable unit, a magnetic field forming unit should be provided in the fixed unit, the movable unit should be swung by electromagnetic force generated by a current flowing to the coil and a magnetic field formed by the magnetic field forming unit, and the beam should serve as a supporter of the movable unit, a conductor for flowing current to the coil, and a spring for returning the movable unit to a reference position.

It is further preferable that the movable unit should be further provided with a light deflecting surface for reflecting incident light to deflect the reflected light and scan with the light.

A characteristic structure of a method of manufacturing a miniature machine according to the present invention is directed to a method of manufacturing a miniature machine including at least one movable unit, a fixed unit and paired beams for supporting the movable unit at the respective ends with respect to the fixed unit and capable of swinging the movable unit about an axis with the beams serving as torsional rotation axes, the method including positioning and disposing the metal elastic member described above in the fixed unit and/or the movable unit in a state where the metal bar and each of the pads are supported by a frame between the fixed unit and the movable unit, fixing the fixed unit and/or the movable unit to each pad and then cutting each support unit, thereby separating the frame.

A characteristic structure of the swing control device according to the present invention is directed to a swing control device for controlling to swing the movable unit of the miniature machine, and the swing control device including an amplitude detector having a light receiving portion for monitoring which detects a monitor light guided from the movable unit along an optical axis having an angle varied with the swinging movement of the movable unit in an inclined direction to a swinging direction with respect to a swinging center direction of the movable unit, and an amplitude detecting circuit for detecting two sections having a long cycle section and a short cycle section which constitute one swing cycle of the movable unit based on the monitor light detected by the light receiving portion for monitoring, and an amplitude controller for variably controlling a frequency while maintaining a current value of a current to be applied to the coil in such a manner that a time ratio of the long cycle section and the short cycle section which are detected by the amplitude detector has a target value.

It is preferable that a first light deflecting surface for deflecting measurement light irradiated from a measurement light source to scan a measurement space and for deflecting reflected light of the measurement light toward a light receiving portion for measurement should be formed on a surface of the movable unit, and a second light deflecting surface should be formed on a back face of the movable unit, the amplitude detector should further include a monitor light source for irradiating monitor light toward the second light deflecting surface, and reflected light thereof should be received by the light receiving portion for monitoring.

It is more preferable that there should be provided a swing phase detector for detecting a swing phase of the movable unit, and a synchronization signal output unit for regulating a measurement time through the measurement light, in synchronization with the swing phase detected by the swing phase detector.

It is further preferable that there should be provided a swing phase detector for detecting a swing phase of the movable unit, and a phase signal output unit for outputting the swing phase detected by the swing phase detector, in synchronization with a measurement time through the measurement light.

A characteristic structure of the swing control method according to the present invention is directed to a swing control method of controlling to swing the movable unit of the miniature machine, the method including detecting a monitor light guided from the movable unit along an optical axis having an angle varied with the swinging movement of the movable unit in an inclined direction to a swinging direction with respect to a swinging center direction of the movable unit, detecting two sections having a long cycle section and a short cycle section which constitute one swing cycle of the movable unit based on the detected monitor light, and vari-

ably controlling a frequency while maintaining a current value of a current to be applied to the coil in such a manner that a time ratio of the long cycle section and the short cycle section which are detected has a target value.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view showing a miniature machine according to the present invention;

FIGS. **2**A to **2**E are views for explaining a process for fabricating a metal elastic member according to the present invention;

FIGS. **3**A to **3**C are views for explaining an attaching process for attaching a movable unit to a fixed unit with the metal elastic member being interposed therebetween;

FIG. **4** is an exploded perspective view showing the miniature machine according to the present invention;

FIG. **5**A is a plan view showing main parts of the movable unit (a coil substrate) and the metal elastic member;

FIG. **5**B is a sectional view showing the main parts of the movable unit (the coil substrate) and the metal elastic member;

FIG. **5**C is a sectional view showing main parts of a movable unit (the coil substrate) and a metal elastic member according to another embodiment.

FIG. **6** is a view for explaining a swinging operation of the movable unit;

FIG. **7** is a view for explaining a site in which the metal elastic member is attached to the fixed unit;

FIG. **8** is an exploded perspective view showing a miniature machine according to another embodiment;

FIG. **9** is a perspective view showing the miniature machine according to another embodiment;

FIG. **10** is a view for explaining a metal elastic member according to another embodiment;

FIG. **11**A is an S-N chart showing a result of a rupture test;

FIGS. **11**B and **11**C are characteristic charts showing a simulation result, illustrating a relationship between a sectional area of a beam and a resonance frequency;

FIG. **12** is a diagram for explaining a swing control device for controlling swing of a movable unit;

FIG. **13** is a chart for explaining a state in which swing amplitude of the movable unit fluctuates;

FIG. **14**A is a chart for explaining the principle of the swing control;

FIG. **14**B is a chart for explaining frequency control on an applied current with respect to a fluctuation in the resonance frequency;

FIG. **15**A is a chart for explaining distance measurement timing upon controlling light emission at equal intervals with respect to a swing angle direction, and control on distance measurement timing upon a fluctuation in a frequency; and

FIG. **15**B is a chart for explaining control on distance measurement timing upon controlling the light emission at equal intervals with respect to a phase direction.

## DESCRIPTION OF THE EMBODIMENTS

A metal elastic member, a miniature machine and a method of manufacturing a miniature machine according to the present invention will be described below with reference to the drawings.

FIGS. **1** and **4** show a miniature machine **1** to be used for a scanning type distance measuring device or the like. The miniature machine **1** includes a frame serving as a fixed unit **2**, a flat plate body serving as a movable unit **3**, paired beams **4**, **4** for supporting the movable unit **3** so as to be swingable about an axis P with respect to the fixed unit **2**, permanent magnets **5** and **6** that are disposed at the respective ends of the movable unit **3** with the beams **4**, **4** being sandwiched therebetween, an upper cover **8**, and the like.

The fixed unit **2** is configured by a rectangular parallelepiped member made of resin such as polycarbonate. An open space is hollowed out in a thickness direction in a slightly larger area than the movable unit **3** as seen on a plane in a central part of the fixed unit **2**, and the movable unit **3** is disposed in the open space.

The beams **4**, **4** are configured by a metal elastic member. The metal elastic member includes a metal bar **4***a* having a predetermined length, a fixed unit pad **4***b* which is provided at a first end of the metal bar **4***a* and is fixed to the fixed unit **2**, and a movable unit pad **4***c* which is provided at a second end of the metal bar **4***a* and is fixed to the movable unit **3**.

The permanent magnets **5** and **6** are disposed opposite to each other in a magnetic retainer **7** taking a sectional shape of "U" and configured by a member having high magnetic permeability in such a manner that the permanent magnet **5** serves as the north pole and the permanent magnet **6** serves as the south pole. The permanent magnets **5** and **6** are inserted from below and fixed into the open space in the fixed unit **2** so as to have the movable unit **3** sandwiched therebetween.

The movable unit **3** includes a deflecting mirror **3***a* that is configured by a glass substrate or a silicon substrate with gold, aluminum, or the like being deposited thereonto, a coil substrate **3***c* that is configured by a glass epoxy substrate with a copper wire coil C and electrode pads E being printed thereon, and a spacer **3***b* that is also made of glass epoxy and is interposed therebetween.

The movable unit pads **4***c* of the paired beams **4**, **4** are positioned so as to be in contact with the electrode pads E, respectively, and are bonded and fixed between the deflecting mirror **3***a* and the coil substrate **3***c* by a conductive adhesive agent. Alternatively, the coil substrate **3***c* may be configured by a multiple layered substrate having substrate layers that are made of epoxy resin or the like, and are provided respectively with coil patterns and coils coupled together by means of a via.

When an alternating current is applied to the coil C through paired beams **4**, **4**, Lorentz force acts on the coil C by the alternating current flowing to the coil C and a magnetic field formed by the permanent magnets **5** and **6** provided on the fixed unit **2** so that the movable unit **3** supported by the beams **4**, **4** is repetitively swung by the Lorentz force.

In other words, the miniature machine **1** includes at least one movable unit **3**, the fixed unit **2** and the paired beams **4**, **4** supporting the movable unit **3** at the respective ends with respect to the fixed unit **2**. The movable unit **3** is configured to be swingable about the axis P with the beams **4** serving as torsional rotation axes. The beams **4**, **4** each serve as a supporter of the movable unit **3**, a conductor for flowing current to the coil C, and a spring for returning the movable unit **3** to a reference position. The movable unit **3** is further provided with a light deflecting surface for reflecting incident light to deflect the reflected light and scan with the light.

A frequency for driving to swing the movable unit **3**, that is, a frequency of the alternating current to be applied to the coil C is preferably set to be a frequency which is slightly shifted from a mechanical resonance frequency of the beams **4**, **4** including the movable unit **3**, and can be set within a range of 10 Hz to approximately 1.8 KHz depending on a size of the movable unit **3**, a sectional area and a length of the metal bar **4***a*, and a physical characteristic thereof.

For example, in the case where an area of a movable mirror is 12 mm×12 mm and the case where the metal elastic mem-

ber according to the present invention is used for the beams **4**, a frequency of 150 Hz to 500 Hz, is suitable.

As shown in FIG. **2**E, in the beams **4**, **4**, a pair of the metal bars **4***a* having the fixed unit pad **4***b* provided at the first end and the movable unit pad **4***c* provided at the second end are disposed symmetrically on a straight line in a frame **40** and the respective pads **4***b* and **4***c* are formed integrally so as to be fixed to the frame **40** through a support unit **41**.

As shown in FIG. **3**A, first of all, paired positioning pins **2***p* provided on the fixed unit **2** are fitted, bonded and fixed into paired positioning hole portions formed on the respective fixed unit pad **4***b*.

As shown in FIG. **3**B, next, paired positioning pins formed on a back face of the deflecting mirror **3***a* are fitted from above paired positioning hole portions provided on the movable unit pad **4***c*, the spacer **3***b* is then put via the open space from below the movable unit pad **4***c*, the positioning pins of the deflecting mirror **3***a* are further fitted into paired positioning hole portions formed on the coil substrate **3***c*, and they are bonded and fixed with an adhesive agent, respectively.

As shown in FIG. **3**C, thereafter, each support unit **41** is cut so that the frame **40** is removed, and an upper cover **8** is further put from above the fixed unit **2** so that the fixed unit pad **4***b* is fixed reliably. The movable unit **3** can be supported in a state in which the linearity of the torsional rotation axis configured by a pair of the metal bars **4***a* is maintained with high accuracy. In addition, an assembling work can also be simplified.

FIGS. **5**A and **5**B show a state in which the electrode pads E formed on the coil substrate **3***c* and the movable unit pads **4***c* provided at the second end of the beams **4**, **4** are positioned and disposed so as to be electrically in contact with each other through the spacer **3***b*. The spacer **3***b* has a central part formed by an insulating member **33** and both ends configured by a metal member **34**. Each of the electrode pads E, E and each of the movable unit pads **4***c*, **4***c* are electrically connected to each other through metal members **34**, **34**. The structure will be described later in detail with reference to FIG. **7**.

As shown in FIG. **3**C, the positioning pin **2***p* provided on the fixed unit **2** is an electrode pin which is configured by a metal and serves to apply an alternating current to the coil C formed on the coil substrate **3***c* through the beams **4**, **4**.

As shown in FIG. **6**, when measurement light formed into parallel light through an optical lens (not shown) from a light emitting device LD such as a laser diode is incident on the deflecting mirror **3***a* and an alternating current is applied to the coil C, the deflecting mirror **3***a* is swung about the axis P with the beams **4**, **4** serving as the torsional rotation axes, the incident light emitted from the light emitting device LD is deflected by the deflecting mirror **3***a* and reflected light is deflected and used to scan at an angle which is a double of a swing angle of the deflecting mirror **3***a*. For example, if the swing angle of the deflecting mirror **3***a* is set to be ±11.25°, the reflected light is used to scan within a scanning angle range of ±22.5°.

The beams **4**, **4** are formed by a physical or chemical processing method excluding a mechanical processing method such as press working by using any of metals including a stainless material, a carbon tool steel material and a cold-reduced carbon steel sheet material which are rolled by a tension annealing method. The tension annealing method indicates treatment for leaving the stainless material or the like for a certain period of time in a nitrogen gas atmosphere containing a hydrogen gas at a high temperature while applying constant tensile stress thereto. For the physical or chemical processing method, there are suitably used a focused ion beam method, an etching method and a plating method (an electroforming method).

FIGS. **2**A to **2**E show a process for fabricating a metal elastic member constituting the beams **4**, **4** by using the etching method according to an example of the chemical processing method. In the present example, a tension annealing material of SUS304CSP-H is used.

A photoresist **43** is uniformly applied onto a surface of a stainless thin plate **42** (see FIG. **2**A) having a predetermined thickness (0.2 mm in the present embodiment) (see FIG. **2**B) and light exposure is carried out through a photomask (not shown) formed in such a manner that regions corresponding to the metal bar **4***a*, the fixed unit pad **4***b*, the movable unit pad **4***c*, the frame **40** and the support unit **41** are shielded (see FIG. **2**C).

When a photoresist **43***b* in the exposed region is removed with a predetermined etchant, a photoresist **43** layer is formed in only regions corresponding to the frame **40** and the beams **4** in the surface of the stainless thin plate **42** (see FIG. **2**D).

Then, an etchant for dissolving stainless is sprayed onto the surface of the stainless thin plate **42** to gradually progress etching treatment. When the etching treatment is completed, the photoresist **43** is removed with a solvent. By the foregoing process, there can be formed a metal elastic member in which a pair of the metal bars **4***a* having the fixed unit pad **4***b* provided at the first end and the movable unit pad **4***c* provided at the second end are disposed symmetrically on a straight line in the frame **40**, and the respective pads **4***b* and **4***c* are formed integrally so as to be fixed to the frame **40** through the support unit **41** (see FIG. **2**E).

In the case where the metal elastic member is fabricated by using the plating method, there is created a mold frame having a predetermined depth in which the photoresist **43** shown in FIG. **2**D takes a shape of a concave portion, a mold release agent is applied onto the mold frame and an electrolytic solution containing a metal ion is then filled therein to electrodeposit a metal in the electrolytic solution. Thus, the metal elastic member can be fabricated.

When the metal bar **4***a* constituting the beam **4** is formed by a mechanical processing (plastic processing) method such as press working or cut working, concentration of a stress is caused by stress amplitude in a plurality of very small scratches formed on the surface in the processing and a crack is thus grown with the very small scratches set as starting points. Consequently, a fatigue strength is reduced. Therefore, the movable unit **3** cannot be swung stably for a long period of time.

If the metal bar **4***a* serving as the beam is formed by using the physical or chemical processing method excluding the mechanical processing method, however, there is a very low probability that such a scratch as to grow a crack might be formed on the surface due to the stress amplitude. Accordingly, there is a very small fear that the fatigue strength might be reduced.

In general, various properties of a metallic material, for example, a yield strength and the like are measured based on a specimen having a diameter of 10 mm (a sectional area of 78.5 $mm^2$) However, a yield strength of a specimen fabricated in at least a dimension of one digit or less (a diameter of 1 mm (a sectional area of 0.785 $mm^2$) or less) of the specimen tends to have a greater value than a published value, and it can be assumed that the sectional area is set to be very small and an effective yield strength thus has a greater value by several tens %.

The following is qualitatively understood. If an existence probability of a scratch on a surface of a target is constant, the

absolute number of scratches to be base points of cracks of a Very High Cycle Fatigue is decreased with reduction in a surface area which is caused by decrease in a size. If a defect probability in an inner part of the target is equal, alternatively, the absolute number of internal defects to be the base points of the cracks of the Very High Cycle Fatigue is decreased with reduction in a volume. As a result, durability or a yield strength is increased.

Although there is a limit, it can be supposed that a smaller substance approximates to an original physical property value of the substance more greatly. The present inventor has confirmed, by an experiment, that a fatigue limit in a torsion direction obtained by a specimen having a diameter of 10 mm has a mechanical angle of ±9.25°, while a metal beam having a section of 0.2 mm×0.25 mm with the use of the same metallic material has a mechanical angle of ±15.5°.

In consideration of the experiential knowledge of the skilled in the art that a maximum stress of a torsional portion is approximately 1.4 times as high as an ordinary stress and a strength is increased by approximately 20% if a sectional dimension is reduced by one digit, a fatigue limit is increased to be approximately 1.2×1.2=1.4 times as high as an ordinary fatigue limit because of a size effect which is smaller by two digits. The increase in the durability and the yield strength is supported by a result obtained through the execution of an experiment from the general qualitative understanding to quantitative understanding.

By molding the metal bar to have a sectional area of 1 $mm^2$ or less, therefore, it is possible to correspondingly constitute a beam exhibiting an excellent effective yield strength. Consequently, the movable unit **3** can be swung stably for a long period of time within a frequency of 150 Hz to 500 Hz. A swing angle of the deflecting mirror **3***a* constituting the movable unit **3** is not limited to be ±11.25° but has a value set properly depending on the intended use of the miniature machine **1**.

It is sufficient that the metal bar **4***a* constituting the beams **4**, **4** shown in FIG. **2**E is formed to have a sectional area of 1 $mm^2$ or less, and it is preferable that the metal bar **4***a* should be molded within a range of 0.001 $mm^2$ to 1 $mm^2$.

In the present embodiment, the metal bar **4***a* is formed to have a width of 1.0 mm, a thickness of 0.2 mm, a length of 5 mm and a sectional area of 0.20 $mm^2$. Each unit of the miniature machine **1** has a size as follows. The fixed unit **2** is formed to have a width of 23 mm, a depth of 26 mm and a thickness of 5.5 mm, and the movable unit **3** is formed to have a width of 12.0 mm, a depth of 12.0 mm and a thickness of 2.0 mm.

FIG. **11**A is an S-N chart showing a result of a rupture test in the case where the beam **4** having a sectional area of 0.05 $mm^2$ and a length of 4 mm is used to swing the deflecting mirror **3***a* having an area of 144 $mm^2$ (12 mm×12 mm) at a driving frequency of 200 Hz (an average resonance frequency: 188.6 Hz).

A white circle indicates a characteristic of a beam configured by the SUS304CSP-H tension annealing material and a black circle indicates a characteristic of a beam configured by the SUS304CSP-H stress release material, and a black triangle indicates a characteristic of a beam configured by a CoNi alloy material subjected to aging treatment (a material which is well-known to have high durability). An optical angle of an axis of ordinates indicates a total swing angle of measurement light. For example, in the case of an optical angle of 60°, the swing angle of the measurement light is ±30° and a swing angle of a deflection plate is ±15°.

As a result of the test, the black circle and the black triangle reach a rupture. On the other hand, although the rupture is reached at an optical angle of 70° or more in the case of the white circle (the tension annealing material), there is no sample reaching the rupture even if 100 million times of a swing cycle are exceeded in the case of an optical angle of 65° or less. As shown in the white circle and the black circle at an optical angle of 62°, it is apparent that a rupture cycle is changed by two digits or more depending on the presence of tension anneal even if suitable stainless SUS304CSP-H is used as a spring material.

FIGS. **11**B and **11**C show a result of a simulation for a resonance frequency in the case where the area of the deflecting mirror **3***a*, the sectional area of the beam and the length of the beam are varied. A simulation parameter is subjected to fitting by a movable mirror produced by way of trial (a condition 1 an area of 12 mm×12 mm, a sectional area of a beam of 0.05 $mm^2$, a beam length of 4 mm and an average measured resonance frequency of 188.6 Hz, and a condition 2=an area of 12 mm×12 mm, a sectional area of a beam of 0.16 $mm^2$, a beam length of 5 mm and an average measured resonance frequency of 400.7 Hz), and a simulation on the other condition is thus executed. It is confirmed that swinging can be carried out with a variation in the resonance frequency from 50 Hz to 1 KHz or more by a change in the shapes of the deflecting mirror and the beam.

FIG. **11**B shows a simulation result based on the condition **1**, that is, a variation in the resonance frequency in the case where the length of the beam is fixed to be 4 mm and the sectional area of the beam is changed. In FIG. **11**B, a sequence 1 is a deflecting mirror of 20 mm×20 mm, a sequence 2 is a deflecting mirror of 16 mm×16 mm, a sequence 3 is a deflecting mirror of 12 mm×12 mm, and a sequence 4 is a movable mirror of 8 mm×8 mm.

FIG. **11**C shows a simulation result based on the condition 2, that is, a variation in the resonance frequency in the case where the length of the beam is fixed to be 5 mm and the sectional area of the beam is changed. In FIG. **11**C, a sequence 1 is a deflecting mirror of 20 mm×20 mm, a sequence 2 is a deflecting mirror of 16 mm×16 mm, a sequence 3 is a deflecting mirror of 12 mm×12 mm, and a sequence 4 is a movable mirror of 8 mm×8 mm.

FIG. **7** shows a positional relationship between the metal elastic member having the fixed unit pad **4***b* and the movable unit pad **4***c* formed on the respective ends of the metal bar **4***a*, and the glass substrate **3***a* to be an upper substrate and the glass epoxy substrate **3***c* to be a lower substrate (for example, the deflecting mirror and the coil substrate) and the spacer **3***b* to be a glass epoxy substrate which constitute the movable unit **3**.

At a bottom face of the upper glass substrate **3***a*, a first groove portion **30** is formed in an orthogonal direction to the axis P, and furthermore, paired second groove portions **31**, **31** are formed in a direction along the axis P. A depth of the first groove portion **30** is slightly greater than the thickness of the movable unit pad **4***c*, and a depth of each of the second groove portions **31**, **31** is further greater than that of the first groove portion **30**.

In a state in which paired positioning pins **3**P formed on the first groove portion **30** is inserted into the positioning hole portion of the movable unit pad **4***c*, the spacer **3***b* is inserted into the first groove portion **30** and is thus bonded so as to have the movable unit pad **4***c* sandwiched between the bottom face of the first groove portion **30** and the upper surface of the spacer **3***b*. Furthermore, paired positioning pins **3**P are positioned to be inserted into paired positioning hole portions formed on the glass epoxy substrate provided below so that the upper glass substrate and lower glass epoxy substrate are bonded to each other.

A metal member is provided to electrically connect both the electrode pads E formed on the coil substrate **3***c* and the movable unit pads **4***c* of the metal elastic member at both ends in the spacer **3***b* where the electrode pads E and the movable unit pads **4***c* are opposed to each other. The spacer **3***b* is configured by disposing an insulating member between paired metal members.

When the first groove portion **30** and the second groove portions **31**, **31** are thus formed on the upper glass substrate **3***a*, the metal bar **4***a* holds its posture in a state in which it does not come in contact with the upper glass substrate **3***a* and lower glass epoxy substrate **3***c*. Consequently, it is possible to eliminate a drawback that the metal bar **4***a* comes in contact with the glass substrate **3***a* and the glass epoxy substrate **3***c* in a torsional operation thereof.

In addition, also in the case where the upper glass substrate **3***a* is caused to serve as a deflecting mirror and an area of a deflection surface is to be increased, it is not necessary to reduce the length of the metal bar **4***a* by employing the structure.

The connecting mode of the beam **4** and the movable unit **3** described with reference to FIGS. **5**A, **5**B and **7** is only illustrative and the connecting mode of the beam **4** and the movable unit **3** according to the present invention is not restricted to the structure.

For example, in the case where the movable unit pads **4***c* are fixed to the vicinity of edge portions of the upper glass substrate **3***a* and lower glass epoxy substrate **3***c* and the metal bar **4***a* is disposed so as not to be covered with the upper glass substrate **3***a* and lower glass epoxy substrate **3***c* as shown in FIG. **5**C, it is sufficient that a concave portion for accommodating the movable unit pad **4***c* is formed on the edge portion of the upper glass substrate **3***a* and a spacer does not need to be provided.

As shown in FIGS. **8** and **9**, moreover, spacer members **3***d* and **3***e* formed of polycarbonate may be inserted between the deflecting mirror **3***a* and the movable unit pad **4***c*, for example, in such a manner that the deflection surface of the deflecting mirror **3***a* is higher than the permanent magnets **5** and **6**. If the deflection surface of the deflecting mirror **3***a* is thus raised, there is no fear that measurement light to be deflected by the deflecting mirror **3***a* might be shielded by rising portions of the permanent magnets **5** and **6** in a swinging movement of the deflecting mirror **3***a*.

FIG. **10** shows a metal elastic member taking a different shape from the metal elastic member described above. The metal bar **4***a* is formed to have a width of 0.1 mm, a thickness of 0.05 mm, a length of 1.50 mm and a sectional area of 0.005 $mm^2$.

It is sufficient that the metal bar **4***a* constituting the metal elastic member according to the present invention is formed to have a sectional area of 1 $mm^2$ or less, and the width, the thickness and the length can be set properly. Moreover, the shapes of the fixed unit pad **4***b* and the movable unit pad **4***c* are not particularly restricted but are preferably adapted to a miniature machine into which they are to be incorporated.

The intended use of the miniature machine according to the present invention is not restricted to a scanning type distance measuring device but can be applied to a device requiring to scan with light, for example, a projector. For instance, it is possible to implement the projector by assembling a light emitting device to the upper glass substrate **3***a* constituting the movable unit **3** and controlling a light emitting state of the light emitting device while swinging the miniature machine in an orthogonal direction to a scanning direction depending on a scanning angle.

Although the description has been given of the miniature machine **1** including the single movable unit **3** supported by paired beams **4**, **4** in the embodiment, it is also possible to employ a structure in which the single miniature machine **1** is provided with the single movable unit **3** supported by paired beams **4**, **4** in plural sets.

In the embodiment, there has been described the example of the metal elastic member, the miniature machine and the method of manufacturing the miniature machine according to the present invention. The technical scope of the present invention is not restricted to the description but it is apparent that the specific structures, sizes and the like of the respective units can be properly changed and designed within a range in which functions and effects according to the present invention can be produced.

Next, description will be given of a swing control device and a swing control method which serve to swing and drive the movable unit of the miniature machine. An application target of the swing control device and the swing control method according to the present invention is not restricted to the miniature machine according to the present invention but can be widely applied to the conventional miniature machines described in Japanese Unexamined Patent Publication Nos. 2003-84226, 9-281417, 2009-175368, and 2008-40228.

As described with reference to FIGS. **1**, **4** and **5**A, the miniature machine to be controlled by the swing control device has a structure in which the coil C is formed in the movable unit **3** supported by the fixed unit **2** through paired beams **4**, **4**, and furthermore, magnetic field forming units **5**, **6** and **7** are provided in the fixed unit **2** to swing the movable unit **3** by electromagnetic force generated by a current flowing to the coil C and magnetic fields formed by the magnetic field forming units **5**, **6** and **7**.

FIG. **12** shows the movable unit **3** incorporated into the miniature machine configured as a distance measuring device. A first light deflecting surface is formed on the surface of the movable unit **3**. The first light deflecting surface serves to deflect measurement light irradiated along an optical path Le from a measurement light source provided in a light receiving and emitting portion **100** and scan a measurement space with the light and to deflect reflected light of the measurement light toward a light receiving portion for measurement provided in the light receiving and emitting portion **100**.

A second light deflecting surface with gold or aluminum deposited thereonto is also formed on the back face of the movable unit **3**, that is, the back face of the coil substrate **3***c*. A monitor light irradiated from a monitor light source **200** disposed on the back face side of the movable unit **3** is guided to the second light deflecting surface along an optical path Lo and reflected light thereof is detected by a light receiving portion **300** for monitoring which is disposed on the back face side of the movable unit **3** in the same manner.

In the case where the monitor light source and the measurement light are used concurrently and the measurement light is thus detected by the light receiving portion for monitoring, it is necessary to install the light receiving portion for monitoring within a scanning range for the measurement light deflected and reflected by the first light deflecting surface and the measurement light deflected and reflected is shielded by the light receiving portion for monitoring so that a measuring range is limited. When amplitude of the movable unit is increased to ensure a predetermined measuring range, therefore, there is caused a problem in that a distortion of the beam is increased and a life is thus shortened.

When the second light deflecting surface for monitoring is formed on the back face of the movable unit **3**, however, it is possible to accurately detect the amplitude without inhibiting

an original function of the movable unit which deflects the measurement light and scans the measurement space with the light. Therefore, it is also possible to require the amplitude of the movable unit at a minimum, thereby preventing the life of the beam from being shortened.

The light receiving and emitting portion **100** and the monitor light source **200** are positioned with respect to the movable unit **3** in such a manner that measurement light sent from the light receiving and emitting portion **100** is incident on the first light deflecting surface of the movable unit **3** in a stationary state at an incident angle of 45° and a monitor light sent from the monitor light source **200** is incident on the second light deflecting surface of the movable unit **3** at an incident angle of 0°.

A laser diode or an LED is suitably used as the monitor light source **200**, and a photodiode or a phototransistor is used as the light receiving portion **300** for monitoring. For example, if the swing angle of the movable unit **3** is ±11.25°, the scanning angle range for the measurement light and the monitor light is ±22.5°, that is, 45°.

The monitor light source **200** and the light receiving portion **300** for monitoring may be incorporated into the miniature machine or may be incorporated into an external case positioned with respect to the miniature machine.

As shown in FIG. **4**, an opening portion **7***a* for guiding the monitor light to the second deflection surface and an opening portion **7***b* for guiding the reflected light to the light receiving portion **300** for monitoring are formed on a bottom portion of the magnetic retainer **7**.

As shown in FIG. **12**, a swing control device **350** includes an amplitude detector **320** having the light receiving portion **300** for monitoring and an amplitude detecting circuit **310**, and an amplitude controller **330**.

The light receiving portion **300** for monitoring detects a monitor light guided from the movable unit **3**, that is, a monitor light along the optical path Lo having an angle varied with the swinging movement of the movable unit **3** in an inclined direction to a swinging direction Dm with respect to a swinging center direction Ds of the movable unit **3**.

The amplitude detecting circuit **310** detects two sections including a long cycle section and a short cycle section which constitutes one swing cycle of the movable unit **3** based on the monitor light detected by the light receiving portion **300** for monitoring.

The amplitude controller **330** variably controls a frequency while maintaining a current value of a current to be applied to the coil C in such a manner that a time ratio of the long cycle section and the short cycle section which are detected by the amplitude detector **320** has a target value.

A detection cycle of the monitor light to be detected by the light receiving portion **300** for monitoring is equal to the swing cycle of the movable unit **3**. In the case where the movable unit **3** is swung from the swinging center direction to a first swinging direction Dm**1** on the side of the light receiving portion **300** for monitoring, the monitor light is detected by the light receiving portion **300** for monitoring in a going movement in which the movable unit **3** is swung toward a maximum swing angle and a return movement in which the movable unit **3** is swung toward a maximum swing angle at an opposite side, and the movable unit **3** is then swung from the swinging center direction Ds to a second swinging direction Dm**2** at an opposite side to the light receiving portion **300** for monitoring and the monitor light is detected by the light receiving portion **300** for monitoring in the return movement from the maximum swing angle at the opposite side.

The amplitude detector **320** detects, as the short cycle section, a detection interval of the monitor light to be detected in the case of the swinging movement from the first swinging direction Dm**1** to the second swinging direction Dm**2**, detects, as the long cycle section, a detection interval of the monitor light to be detected in the case of the swinging movement from the second swinging direction to the first swinging direction, and detects a total time including the short cycle section and the long cycle section as a one cycle of the movable unit **3**.

Specifically, the amplitude detector **320** includes a comparator for binarizing a monitor light with a predetermined threshold, a timer circuit for triggering a signal edge detected by the comparator, thereby counting each of times for a short cycle section and a long cycle section, a storage portion for storing a value of the timer circuit, and the like.

In an upper part of FIG. **13**, there are shown an amplitude characteristic curve (a solid line) in the case where the movable unit **3** has target amplitude A (at this time, a swing angle is +11.25°), an amplitude characteristic curve (a broken line) in the case where the movable unit **3** has amplitude A' larger than the target amplitude A (at this time, the swing angle is greater than +11.25°), and an amplitude characteristic curve (a dashed line) in the case where the movable unit **3** has amplitude A" smaller than the target amplitude A (at this time, the swing angle is smaller than +11.25°), and furthermore, there is shown swing amplitude "a" in which the monitor light is reflected toward the light receiving portion **300** for monitoring.

In a lower part of FIG. **13**, there is shown timing for detecting the monitor light by the light receiving portion **300** for monitoring. Ideally, it is preferable that the movable unit **3** should be swung continuously at the target amplitude A. When the resonance frequencies of the beams **4**, **4** including the movable unit **3** are changed due to a fluctuation in an environmental temperature or the like, however, the amplitude is shifted from the target amplitude A. The amplitude of the movable unit **3** is increased when the resonance frequency approximates to the frequency of the current to be applied to the coil C, and the amplitude of the movable unit **3** is reduced when the resonance frequency keeps away from the frequency of the current to be applied to the coil C.

When the movable unit **3** has the target amplitude A, the amplitude detector **320** detects a short cycle section T**11** and a long cycle section T**12** and detects a total time T**1** of the short cycle section T**11** and the long cycle section T**12** as one cycle of the movable unit **3**.

When the movable unit **3** has the amplitude A' which is greater than the target amplitude A, the amplitude detector **320** detects a short cycle section T**21** and a long cycle section T**22** and detects a total time T**2** (=T**1**) of the short cycle section T**21** and the long cycle section T**22** as one cycle of the movable unit **3**.

When the movable unit **3** has the amplitude A" which is smaller than the target amplitude A, similarly, the amplitude detector **320** detects a short cycle section T**31** and a long cycle section T**32** and detects a total time T**3** (=T**1**) of the short cycle section T**31** and the long cycle section T**32** as one cycle of the movable unit **3**.

If the time ratio of the long cycle section and the short cycle section which are detected by the amplitude detector **320** is shifted from a target value (T**11**/T**12**), the amplitude controller **330** variably controls a frequency f while constantly maintaining the current value of the current to be applied to the coil C in such a manner that the time ratio has the target value (T**11**/T**12**).

As a result, the amplitude of the movable unit **3** is constantly maintained to be the target amplitude A. Specifically, the amplitude controller **330** includes an arithmetic circuit for

calculating a deviation between the time ratio of the long cycle section and the short cycle section and the target value of the time ratio, a feedback calculating portion illustrated as a PID calculation, or the like for calculating a control value of a frequency of an applied current based on the deviation, an AC power supply circuit, and the like having a PLL circuit for regulating the frequency of the applied current correspondingly to the control value calculated by the feedback calculating portion. To constantly maintain the current value of the current to be applied to the coil C implies that an effective value of an alternating current is maintained to be constant.

As shown in FIG. **14**A, there is assumed the case where the amplitude detector **320** detects a monitor light at a position of amplitude αA, for each of the movable units **3** having the same swing amplitude A and swing frequencies f**1** and f**2** (f**1**<f**2**), respectively.

The movable unit **3** having the swing frequency f**1** is swung in A**1**(t)=A sin 2πf**1***t* and the movable unit **3** having the swing frequency f**2** is swung in A**2**(t)=A sin 2πf**2***t*. Times t**11**, t**12** and t**13** in which the amplitude reaches αA are found in the following equations.

$$t11=\{1/(2\pi f1)\}\times\sin^{-1}(\alpha)$$

$$t12=\{1/(2\pi f1)\}\times\{\pi\times\sin^{-}(\alpha)\}$$

$$t13=\{1/(2\pi f1)\}\times\{2\pi\times\sin^{-1}(\alpha)\}$$

are found from

$$\alpha A=A\sin 2\pi f1t$$

$$\alpha A=A\sin 2\pi f2t$$

wherein $0\leq\sin^{-1}(\alpha)\leq\pi/2$ is set.

Accordingly,

$$T11=t12-t11=\{1/(2\pi f1)\}\times\{\pi-2\sin^{-1}(\alpha)\}$$

$$T12=t13-t12=\{1/(2\pi f1)\}\times\{\pi+2\sin^{-1}(\alpha)\}$$

$$T11/T12=\{\pi-2\sin^{-1}(\alpha)\}/\{\pi+2\sin^{-1}(\alpha)\}$$

are obtained, and similarly

$$T21/T22=\{\pi-2\sin^{-1}(\alpha)\}/\{\pi+2\sin^{-1}(\alpha)\}$$

is obtained.

In other words, if the amplitude is equal, T**1**/T**2** (=T**11**/T**12**=T**21**/T**22**) is constant even though the frequency is varied. To the contrary, if the frequency is regulated in such a manner that T**1**/T**2** is constant, the amplitude is maintained to be constant.

As shown in FIG. **14**B, in the case where an original resonance frequency of the beams **4**, **4** including the movable unit **3** is represented by Qb, the amplitude controller **330** constantly maintains the current to be applied to the coil C in an early stage, and at the same time, a frequency of the current is changed continuously or gradually from a frequency fmax which is sufficiently higher than the resonance frequency Qb to a frequency fmin which is sufficiently lower than the resonance frequency Qb.

The amplitude controller **330** decides, at each time, whether the time ratio of the long cycle section and the short cycle section which are detected by the amplitude detector **320** has the target value or not, and maintains the frequency (a frequency indicated as fb in FIG. **14**B) if the time ratio converges on a predetermined tolerance. In FIG. **14**B, an operating point of the movable unit **3** is indicated as a Pb point of a resonance characteristic of the resonance frequency Qb.

Then, the operating point is changed to a P**1** point of a resonance characteristic of a resonance frequency Q**1** so that the amplitude is decreased when the resonance frequency is reduced to Q**1**, and the operating point is changed to a Ph point of a resonance characteristic of a resonance frequency Qh so that the amplitude is increased when the resonance frequency is increased to Qh.

For example, in the case where the resonance frequency is increased to Qh, the amplitude controller **330** regulates the frequency of the current to be applied to the coil C into fh**1** which is higher than the resonance frequency Qh or fh**2** which is lower than the resonance frequency Qh in such a manner that the time ratio of the long cycle section and the short cycle section has the target value.

As a result, the movable unit **3** is operated on a Ph**1** point or a Ph**2** point of the resonance characteristic of the resonance frequency Qh. In the case where the stability of the operation exhibits a difference on the Ph**1** point or the Ph**2** point, it is preferable to carry out the regulation into either of the operating points which has the higher stability of the operation.

In actual trial fabrication, a high frequency side of a resonance point has the higher stability. For this reason, scanning is always carried out from the frequency fmax side to set the operating point. In this case, accordingly, it is possible to maintain the amplitude to have the target value by raising the frequency with increase in the amplitude and reducing the frequency with decrease in the amplitude. In the case of FIG. **14**B, the operating point is moved to the Ph**1** point.

In other words, the swing control method according to the present invention serves to detect a monitor light guided from the movable unit **3**, that is, a monitor light along the optical path having an angle varied with the swinging movement of the movable unit **3** in an inclined direction to the swinging direction Dm with respect to the swinging center direction Ds of the movable unit **3**, to detect two sections including the long cycle section T**12** and the short cycle section T**11** which constitute one swing cycle of the movable unit **3** based on the monitor light thus detected, and to variably control a frequency while maintaining the current value of the current to be applied to the coil C in such a manner that the time ratio T**11**/T**12** (or T**12**/T**11**) of the long cycle section T**12** and the short cycle section T**11** which are detected has a target value.

Each "light receipt timing" shown in FIG. **13** has been described by taking, as an example, a waveform obtained by using a laser diode for a monitor light source, binarizing a signal of the monitor light detected by the light receiving portion **300** for monitoring through the comparator and detecting a rising edge as each light receipt timing by the amplitude detector **320**.

As with an analog signal waveform shown by a solid line of a "reference light receipt timing" in FIG. **13**, however, in some cases in which a light source having a comparatively great light beam such as an LED is used for the monitor light source, a signal waveform corresponding to the monitor light detected by the light receiving portion **300** for monitoring becomes blunt so that rising edges corresponding to t**31** and t**32** cannot be detected in the short cycle section, for example.

In this case, a threshold for binarization is decreased so that a rising edge t**31**' and a falling edge t**32**' in the short cycle section can be substituted for values corresponding to t**31** and t**32**.

In the case of an analog signal, a luminous efficiency or a light reception sensitivity is varied with a change in a temperature. For this reason, an electrical light receiving signal level is changed as shown a broken line of the "reference light receipt timing" in FIG. **13**. It is possible to prevent the influence of a temperature change by properly varying a ratio of a short cycle period and a long cycle period depending on a

temperature or changing a threshold for binarization in the case where control is carried out in the analog signal waveform.

Another preferred embodiment of the swing control device **350** will be described below.

It is preferable to include a swing phase detector for detecting a swing phase ϕ of the movable unit **3** and a synchronization signal output unit for regulating a measurement time through measurement light in synchronization with the swing phase ϕ detected by the swing phase detector.

The distance measuring device includes a distance measurement calculating portion for calculating a distance to a reflecting position (an object) of measurement light based on a phase difference or a time difference from reflected light detected subsequently on the basis of an emission time of measurement light from the measurement light source provided in the light receiving and emitting portion **100**. For example, the distance measurement calculating portion employing a TOF method carries out lighting control over the measurement light source in a predetermined cycle to calculate a distance to the object, and specifies coordinates of the object from the distance at that time and an emitting direction of the measurement light.

If the cycle of the movable unit **3** and the emission time of the measurement light are shifted from each other, however, it is impossible to accurately obtain the coordinates of the object by the distance measurement calculating portion. In other words, there is the following fear. Specifically, a measuring direction is varied if the swing cycle of the movable unit is changed in order to control the amplitude of the movable unit to be constant in a state in which a measuring cycle (a lighting cycle) utilizing measurement light is maintained to be constant. Consequently, it is impossible to obtain a measured value corresponding to a measuring direction which is originally necessary. Moreover, there is also a fear that the number of necessary measured values in the swing cycle might be increased/decreased.

Also in that case, the distance measurement calculating portion can regulate a measurement time through measurement light based on a synchronization signal synchronized with a swing phase which is output from a synchronization signal output unit. Even if the swing cycle of the movable unit is varied, it is possible to reliably obtain the measured value corresponding to the measuring direction which is originally necessary.

As shown in FIG. **14**A, for example, the amplitude is maximized at a time for a half of each of the long cycle section T**12** and the short cycle section T**11** which are detected by the amplitude detector **320**. The swing phase detector can detect a time for the half of each of the sections by counting a time since starting stages of the long cycle section T**12** and/or the short cycle section T**11** which are/is detected by the amplitude detector **320**.

In other words, the time for the half of the short cycle section T**11** can be detected as a time that a phase π/2 is obtained, and furthermore, the time for the half of the long cycle section T**12** can be detected as a time that a phase 3π/2 is obtained. Moreover, a time acquired by going back, by (¼)×T**1** hours, from the time that the phase of π/2 is obtained can be detected as a time that a phase of 0 is obtained.

The synchronization signal output unit outputs, to the distance measurement calculating portion, a synchronization signal corresponding to a predetermined swing phase based on the swing phase of the movable unit **3** which is detected by the swing phase detector. Even if the swing cycle of the movable unit **3** fluctuates, consequently, it is possible to carry out a distance measurement calculation by always turning on measurement light for distance measurement corresponding to the predetermined swing phase.

As shown in FIG. **15**A, if a phase in the case where the movable unit **3** swung at the frequency f**1** needs to measure a distance in a direction of a swing angle An is represented by ϕn, it is preferable to measure a distance at a phase angle which satisfies An=A×sin (ϕn). In the case of the frequency f**1**, a time t**1***n* is obtained in accordance with t**1***n*=(ϕn/2π)×T**1**. At this time, it is preferable to measure a distance.

In the case where the resonance frequency fluctuates and the movable unit is swung at the frequency f**2**, the measurement light is sent in a direction having a swing angle An' if a distance is measured at the same time t**1***n*. Consequently, it is impossible to measure a distance in an intended direction. Also in this case, the phase ϕn which is to be subjected to the distance measurement is identical. Therefore, a measurement time t**2***n* in the case of the frequency f**2** can be found by t**2***n* = (ϕn/2π)×T**2**.

Based on the time for the phase of 0 detected by the phase detector **320** and a time for one cycle, thus, it is possible to calculate the time an corresponding to the phase ϕn in the case of the frequency f**1**, thereby outputting a synchronization signal. Also in the case where the frequency fluctuates to f**2**, it is possible to measure a distance in the predetermined phase ϕn at a swing angle An by outputting the synchronization signal to the time t**2***n* corresponding to the phase ϕn.

In other words, the swing angle of the movable unit **3** fluctuates into An' when the amplitude controller **330** controls the frequency to be the frequency f**2**. If the synchronization signal is output, by the synchronization signal output unit, at the time t**2***n* that the movable unit **3** has the phase ϕn, however, the distance measurement calculating portion can turn on measurement light at the time t**2***n* that the swing angle of the movable unit **3** is An.

FIG. **15**A is a chart showing distance measurement timing in the case where light emission control is carried out at equal intervals with respect to a swing angle direction or a scanning direction, and FIG. **15**B is a chart showing distance measurement timing in the case where the light emission control is carried out at equal intervals in a phase direction or on a time base. A phase or time for the execution of the light emission control is properly determined depending on an intended use and is not restricted to the example. Moreover, light emission timing may be preset, to a storage device in a control device, as information about a phase in which the light emission is to be executed or information corresponding thereto or may be input from an external control device or the like.

If there are provided a swing phase detector for detecting a swing phase of the movable unit **3** and a phase signal output unit for outputting the swing phase detected by the swing phase detector in synchronization with a measurement time through measurement light, moreover, it is possible to grasp the swing phase of the movable unit which is synchronized with the measurement time through the measurement light on the basis of the phase signal output from the phase signal output unit. Therefore, it is possible to specify a corresponding direction to a measured value accurately.

In the case where the miniature machine is set to be a light scanning mechanism in a vertical direction and is combined with another driving device in a horizontal direction to carry out two-dimensional light scanning, furthermore, it is necessary to perform control in order to scan phases of the two scanning mechanisms synchronously when detection accuracy needs to be constantly maintained. If the phase signal output unit is provided also in this case, it is possible to easily control a phase of the driving device in the horizontal direction by using the phase signal. The phase signal can be

selected appropriately if it is a signal related to a phase, for example, a synchronization signal indicative of a phase of zero, time information about one cycle or the like.

Both the synchronization signal output unit and the phase signal output unit may be provided in the swing control device **350**, and a switching portion (for example, a change-over switch) for switching either of them to function may be provided.

The specific circuits constituting the respective functional blocks in the swing control device **350** are not particularly restricted but it is possible to properly constitute them by using an analog signal circuit, a digital signal circuit, a gate array, a microcomputer and the like which are well-known.

What is claimed is:

**1**. A method of manufacturing a miniature machine including at least one movable unit, a fixed unit and paired beams for supporting the movable unit at the respective ends with respect to the fixed unit and capable of swinging the movable unit about an axis with the beams serving as torsional rotation axes,

the method comprising the steps of:

positioning and disposing a metal elastic member in the fixed unit and/or the movable unit in a state in which the metal bar and each of the pads are supported by the frame, the metal elastic member including a metal bar molded to have a sectional area of 1 $mm^2$ or less by using a physical or chemical processing method excluding a mechanical processing method and having a predetermined length which swings the movable unit, a fixed unit pad that is provided at a first end of the metal bar and is fixed to the fixed unit, a movable unit pad that is provided at a second end of the metal bar and is fixed to the movable unit, and a frame, and having a pair of the metal bars disposed symmetrically on a straight line in the frame and a plurality of support units for coupling the frame to each of the pads formed integrally by using the physical or chemical processing method excluding the mechanical processing method;

fixing the fixed unit and/or the movable unit to each of the pads; and

cutting each of the support units to separate the frame after fixing the fixed unit and/or the movable unit to each of the pads.

**2**. A swing control device for controlling to swing a movable unit of a miniature machine,

for the miniature machine including at least one movable unit having a coil formed thereon, at least one fixed unit having a magnetic field forming unit provided thereon, and paired beams having a metal bar which is molded to have a sectional area of 1 $mm^2$ or less by using a physical or chemical processing method excluding a mechanical processing method, supporting the movable unit at the respective ends with respect to the fixed unit and supporting the movable unit so as to be swingable about an axis with the metal bar serving as a torsional rotation axis, that is, paired beams to serve as a conductor for flowing current to the coil and to serve as a spring for returning the movable unit to a reference position, and configured in such a manner that the movable unit is swung by electromagnetic force generated by a current flowing to the coil via the beam and a magnetic field formed by the magnetic field forming unit,

the swing control device comprising:

an amplitude detector including a light receiving portion for monitoring which detects a monitor light guided from the movable unit, that is, a monitor light along an optical axis having an angle varied with a swinging movement of the movable unit in an inclined direction to a swinging direction with respect to a swinging center direction of the movable unit, an amplitude detecting circuit for detecting two sections having a long cycle section and a short cycle section which constitute one swing cycle of the movable unit based on the monitor light detected by the light receiving portion for monitoring; and

an amplitude controller for variably controlling a frequency while maintaining a current value of a current to be applied to the coil in such a manner that a time ratio of the long cycle section and the short cycle section which are detected by the amplitude detector has a target value.

**3**. The swing control device according to claim **2**, wherein

a first light deflecting surface for deflecting measurement light irradiated from a measurement light source and scanning a measurement space with the measurement light and for deflecting reflected light of the measurement light toward a light receiving portion for measurement is formed on a surface of the movable unit, and a second light deflecting surface is formed on a back face of the movable unit, and

the amplitude detector further includes a monitor light source for irradiating a monitor light toward the second light deflecting surface, and reflected light thereof is received by the light receiving portion for monitoring.

**4**. The swing control device according to claim **3** more comprising:

a swing phase detector for detecting a swing phase of the movable unit; and

a synchronization signal output unit for regulating a measurement time through the measurement light in synchronization with the swing phase detected by the swing phase detector.

**5**. The swing control device according to claim **3** more comprising:

a swing phase detector for detecting a swing phase of the movable unit; and

a phase signal output unit for outputting the swing phase detected by the swing phase detector in synchronization with a measurement time through the measurement light.

**6**. A swing control method of controlling to swing a movable unit of a miniature machine,

for the miniature machine including at least one movable unit having a coil formed thereon, at least one fixed unit having a magnetic field forming unit provided thereon, and paired beams having a metal bar which is molded to have a sectional area of 1 $mm^2$ or less by using a physical or chemical processing method excluding a mechanical processing method, supporting the movable unit at the respective ends with respect to the fixed unit and supporting the movable unit so as to be swingable about an axis with the metal bar serving as a torsional rotation axis, that is, paired beams to serve as a conductor for flowing current to the coil and to serve as a spring for returning the movable unit to a reference position, and configured in such a manner that the movable unit is swung by electromagnetic force generated by a current flowing to the coil via the beam and a magnetic field formed by the magnetic field forming unit,

the method comprising the steps of:

detecting a monitor light guided from the movable unit, that is, a monitor light along an optical axis having an angle varied with a swinging movement of the movable

unit in an inclined direction to a swinging direction with respect to a swinging center direction of the movable unit;

detecting two sections having a long cycle section and a short cycle section which constitute one swing cycle of the movable unit based on the detected monitor light; and

variably controlling a frequency while maintaining a current value of a current to be applied to the coil in such a manner that a time ratio of the long cycle section and the short cycle section which are detected has a target value.

**7**. A metal elastic member to be used for paired beams for supporting a movable unit at respective ends with respect to a fixed unit in a miniature machine including at least one movable unit, the fixed unit and the beams, and capable of swinging the movable unit about an axis with the beams serving as torsional rotation axes,

the metal elastic member comprising:

a metal bar molded to have a sectional area of 1 $mm^2$ or less by using a physical or chemical processing method excluding a mechanical processing method and having a predetermined length which swings the movable unit;

a fixed unit pad that is provided at a first end of the metal bar and is fixed to the fixed unit; and

a movable unit pad that is provided at a second end of the metal bar and is fixed to the movable unit,

wherein the metal elastic member is configured by either a stainless material, a carbon tool steel material, or a cold-reduced carbon steel sheet material which are rolled by a tension annealing method.

**8**. The metal elastic member according to claim **7**, wherein the physical or chemical processing method includes a focused ion beam method, an etching method, and a plating method.

**9**. A method elastic member to be used for paired beams for supporting a movable unit at respective ends with respect to a fixed unit in a miniature machine including at least one movable unit, the fixed unit and the beams, and capable of swinging the movable unit about an axis with the beams serving as torsional rotation axes,

the metal elastic member comprising:

a metal bar molded to have a sectional area of 1 $mm^2$ or less by using a physical or chemical processing method excluding a mechanical processing method and having a predetermined length which swings the movable unit;

a fixed unit pat that is provided at a first end of the metal bar and is fixed to the fixed unit; and

a movable unit pad that is provided at a second end of the metal bar and is fixed to the movable unit,

wherein a frame, a pair of the metal bars disposed symmetrically on a straight line in the frame, and a plurality of support units for coupling the frame to each of the pads are formed integrally by using the physical or chemical processing method excluding the mechanical processing method.

**10**. The metal elastic member according to claim **9**, wherein the physical or chemical processing method includes a focused ion beam method, an etching method, and a plating method.

**11**. A miniature machine comprising:

a movable unit;

a coil formed in the movable unit;

a fixed unit;

a magnetic field forming unit provided in the fixed unit; and

paired beams including a metal bar which is molded to have a sectional area of 1 $mm^2$ or less by using a physical or chemical processing method excluding a mechanical processing method, supporting the movable unit at the respective ends with respect to the fixed unit and supporting the movable unit so as to be swingable about an axis with the metal bar serving as a torsional rotation axis, a beam of the paired beams serving as a supporter of the movable unit, a conductor for flowing current to the coil, and a spring for returning the movable unit to a reference position,

wherein

the movable unit is swung by electromagnetic force generated by a current flowing to the coil via the beam and a magnetic field formed by the magnetic field forming unit, and

the beam is configured by either a stainless material, a carbon tool steel material, or a cold-reduced carbon steel sheet material which are rolled by a tension annealing method.

**12**. The miniature machine according to claim **11**, wherein the physical or chemical processing method includes a focused ion beam method, an etching method, and a plating method.

**13**. The miniature machine according to claim **11**, further comprising

a light deflecting surface formed in the movable unit and reflecting incident light to scan.

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